12-2015

Industrial Energy Consumption, Benchmarking, and Analysis in the United States

Daniel Maldonado
University of Arkansas, Fayetteville

Industrial Energy Consumption, Benchmarking, and Analysis in the United States

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING
COLLEGE OF ENGINEERING

BY

Daniel Maldonado

December, 2015
University of Arkansas
Fayetteville, AR

Dr. Rick J. Couvillion
Thesis Director

Dr. Larry A. Roe
Committee Member

Dr. Darin W. Nutter
Committee Member

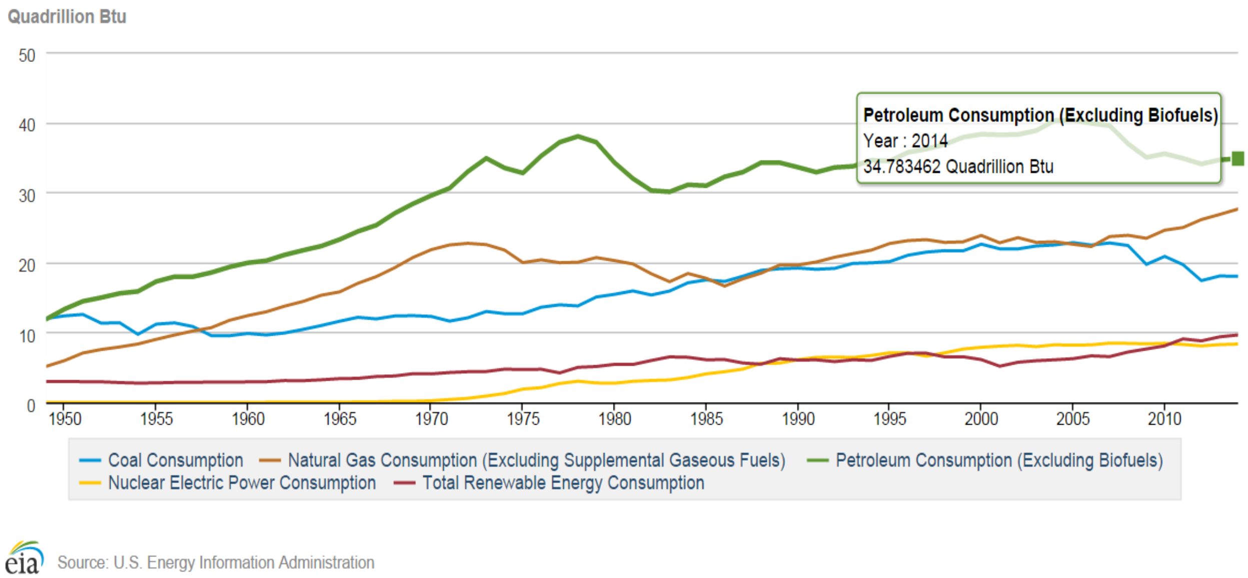
Table of Contents

Background

Energy conservation has become crucial for both the industrial and the residential areas for several reasons. “About one-third of the energy used in the United States in 2006 went to industry. That’s not so surprising when you consider everything that falls under this economic sector. Every product we rely on—from aluminum cans to fertilizer to glass to paper products—takes energy to produce. The use of energy in industry affects every single citizen personally through the cost of goods and services, the quality of manufactured products, the strength of the economy, and the availability of jobs.”[15] In the industrial sector, conservation of energy is a matter of staying competitive against other companies. Enormous monetary savings can emerge from conservation of energy. In addition, energy prices are linked to foreign sources. For that reason, controlling and minimizing energy consumption can reduce the risk of being hit by an unpredictable increase of energy price. Also, environmental impact has also been increasing in the past years. Improving energy efficiency is the most effective way to limit the impact to the environment. For these reasons, and for numerous others, companies and industries in the United States have been working to control the amount of their energy consumption.

Industrial energy benchmarking has become very important since the industrial sector, compared with the residential, commercial, and transportation sector, has been the largest energy consumer in history. For each company in the United States it is important to know how well they are doing compared to other similar facilities. Several tools are used by these companies to measure their performance. These tools have been helping to improve industrial energy consumption, lowering the amounts of energy used at the beginning of the 21st century. It is also important to understand that the other sectors mentioned have increased their energy consumption, instead of trying to minimize it, but this paper is focused solely on the analysis of the industrial sector, and the tools used by this sector to minimize their consumption. [1]

Energy Consumption



Graph 1 Primary Energy Consumption by Source.[2]

In history, United States energy consumption has been increasing. In 1950, according to the U.S. Energy Information Administration (EIA), the total energy consumption was 34.615768 quadrillion Btus. In contrast, in 2014, the United States consumed around 98.459794 quadrillion Btus of energy throughout the year. The main sources used to produce energy are coal, natural gas, petroleum, nuclear power, and now, in modern times, the production of alternative renewable energy has been increasing. During the same year, the industry sector's total consumption of energy was 31307.706 trillion Btus. This represents the 32% of the total energy consumed. [2]

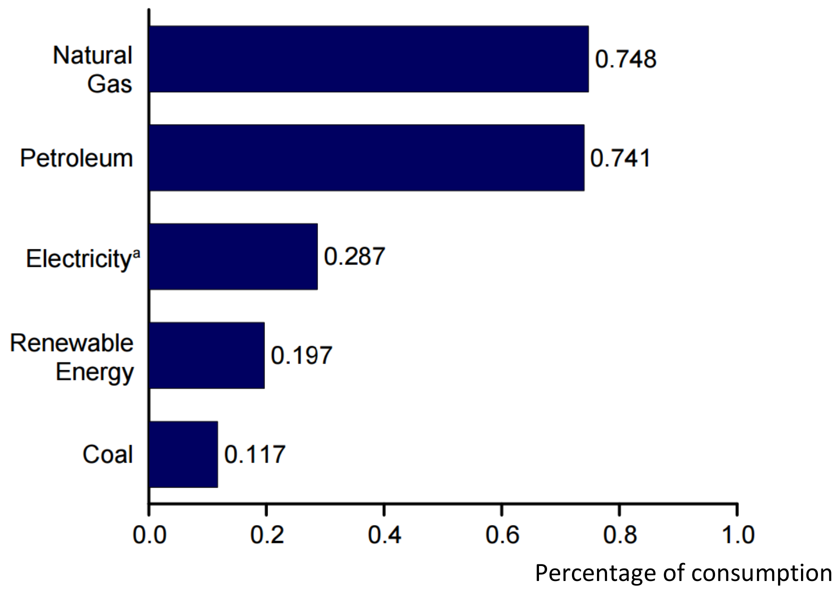
An overview of the primary consumption, production, and trade of energy will provide a better understanding of the current energy situation that the United States is going through. It would be rational to think that in order to supply the consumption of energy in all the different sectors, the production has to be larger than the consumption. This is not the case in many countries in the world, including the United States. According to the EIA, 1957 was the last year the production of energy was larger than the consumption. As a matter of fact, it was during that time when the United Stated started importing more energy than the one that was being exported. This is somewhat obvious, given that the country had to find a way to supply the demand of energy. 2005, in my opinion, was an important year in terms of the energy situation in the country, because the difference between the produced and imported energy was smaller than the total consumed and exported energy.

Table 1 U.S. Energy Consumption, 1950 – 2013 [8]

	Energy Consumption by Sector (Quadrillion Btu)						Consumption Per Capita (Million Btu)		
	Resid.	Comm.	Indust.	Trans.	Total	Population (millions)	Total	Resid.	Trans.
1950	6.0	3.9	16.2	8.5	34.6	152.3	227.3	39.3	55.8
1955	7.3	3.9	19.5	9.6	40.2	165.9	242.3	43.9	57.6
1960	9.0	4.6	20.8	10.6	45.1	180.7	249.5	50.0	58.6
1965	10.6	5.8	25.1	12.4	54.0	194.3	278.0	54.8	64.0
1970	13.8	8.3	29.6	16.1	67.8	205.1	330.8	67.1	78.5
1975	14.8	9.5	29.4	18.2	72.0	216.0	333.2	68.6	84.5
1980	15.8	10.6	32.0	19.7	78.1	227.2	343.6	69.3	86.7
1985	16.0	11.5	28.8	20.1	76.4	237.9	321.1	67.4	84.4
1990	16.9	13.3	31.8	22.4	84.5	249.6	338.5	67.9	89.8
1995	18.5	14.7	34.0	23.8	91.0	266.3	341.9	69.5	89.6
2000	20.4	17.2	34.7	26.5	98.8	282.2	350.2	72.4	94.1
2005	21.6	17.9	32.4	28.4	100.3	295.5	339.3	73.2	95.9
2010	21.9	18.1	30.5	27.6	98.0	309.3	316.9	70.6	88.8
2011	21.4	18.0	30.8	27.2	97.5	311.6	312.8	68.7	86.9
2012	20.0	17.4	30.9	26.8	95.0	313.9	302.6	63.6	85.3
2013	21.1	17.9	31.5	27.0	97.5	316.2	308.4	66.8	85.4

As stated on the EIA website, the United States consumed about 0.55 quadrillion Btu's more than it was supposed to. It is important to stress that this did not mean a major economic loss, such as the one that occurred during the energy crisis in the 1970s, since aggregate indicators of total energy production and consumption do not adequately reflect the complexity of the price variations of oil, natural gas, and the different energy sources. In this paper, I will analyze the industrial sector consumption of energy by each individual source of production. Table 1 gives the general information about the total consumption of energy from 1950 to 2013 in the United States. [6] It is possible to see that the industrial consumption has been increasing until 2000. Then, in 2005, a drop in the consumptions occurred, as previously stated. In addition, it is very important to highlight that the industrial sector is the one that consumes the most energy in the United States.

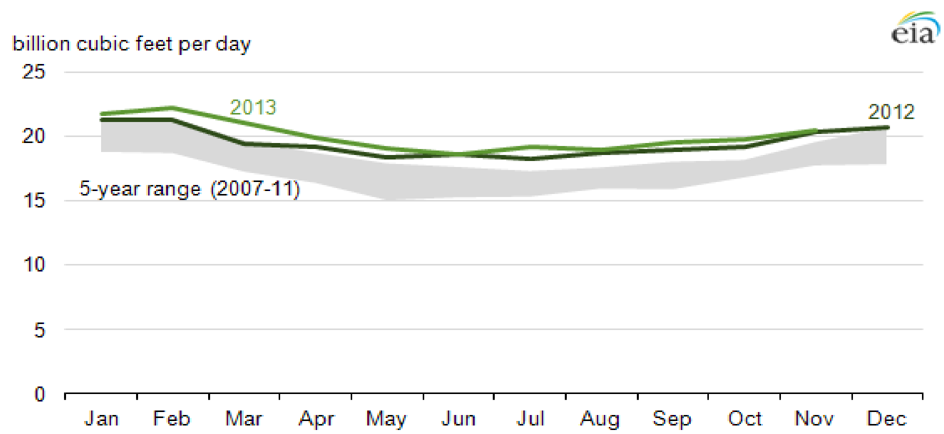
As the largest energy consumer in the country, the industrial sector has been supplying its demand of energy mainly from two sources in the past years. Around the 50s, coal was the major source, but today petroleum and natural gas are, by far, the major energy sources for the industry in the United States. Graph 2 represents the amount of energy by source consumed by the industrial sector until July of this year. It is clear that natural gas and petroleum individually provide as much energy as the rest of the sources combined to the United States' industry.



Graph 2 Industrial Sector Energy Consumption by Major Source until July 2015 [9]

Natural Gas

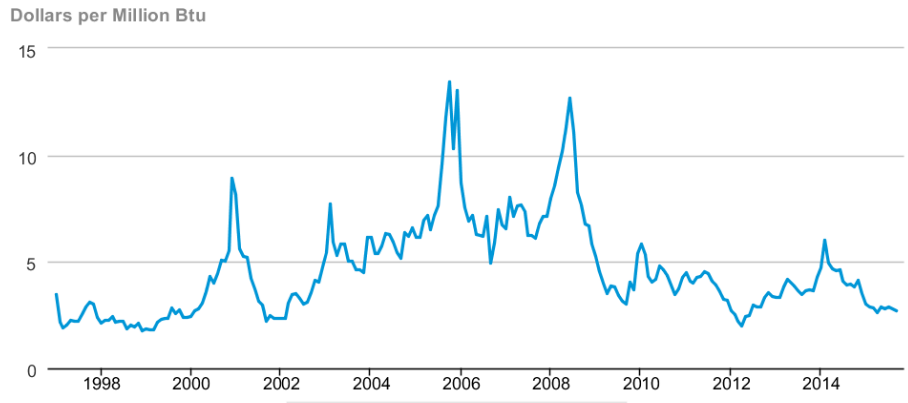
Natural gas consumption has been increasing significantly throughout the years. Since the end of the 1950s, when coal stopped being the industrial sector's most-used source of energy, natural gas and petroleum became the leading sources. Since it is the most used energy source by the industrial sector today, it makes sense to start analyzing its consumption, as well as the reasons why it is one of the industrial sector's preferences. According to Ratner and Glover in their report for the Congressional Research Center, the United States consumed about 26.04 trillion cubic feet of natural gas in 2013. The industrial sector represented 34.1% of the total consumption, making it the sector with the largest percentage of natural gas consumption. It is important to notice that in 1950s, the industrial sector's consumption of natural gas represented more than 50% of the total consumption. [8]



Graph 3 Industrial Consumption of Natural Gas 2012-2013 [11]

In the past decade, the electric power sector started consuming more natural gas. In 2012, as a matter of fact, this sector consumed a larger percentage than the industrial sector, in terms of total natural gas consumption. Lately, however, the consumption of natural gas by the electric power sector started falling, while the industrial sector's use continued to rise. Graph 3 represents the consumption in billion cubic feet (Bcf/d), and it is possible to see that, until November, the natural gas consumed each month in 2013 is larger than the amount consumed each month in 2012. Around 2011, all the industrial facilities with the ability to change from oil to natural gas decided to do so. The main reason was because "at that time natural gas prices in the United States, relative to those in Japan and Europe have made U.S. energy-intensive industries more competitive globally, allowing them to capture a larger share of global markets." [10] In 2014, an increase of natural gas occurred, but did not have a major effect, since it dropped very quickly once again. In 2015, according to the Henry Hub natural gas pricing, the price of natural gas in the United States started at USD2.99 per million Btus, and fell from there. During the month of October and November, the price fluctuated between USD2.18 – 2.50 per million Btu. Graph 4 gives a better graphic representation of the natural gas price history for the past 16 years in the United States. In conclusion, the main reason the largest source of energy in the industrial sector is natural gas is because the price in the United

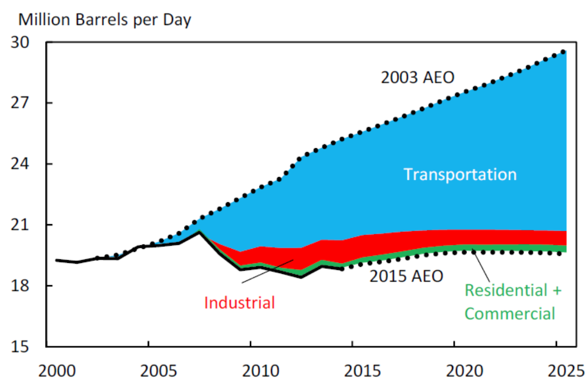
States is beneficially low, increasing the industrial sector's competitiveness around the world. [11][12]



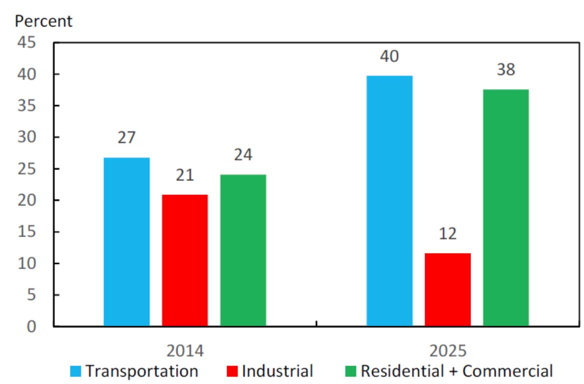
Graph 4 Henry Hub Natural Gas Spot Price [12]

Oil & Petroleum

Oil production in the United States started to increase in 2008, after falling for over 35 years since 1970. In 2008, oil production increased from 5 million barrels per day (b/d) to 8.3 b/d. This increase occurred mainly due to the growth of technological innovations, which placed the United States, unexpectedly, as the leader in oil production. On the other hand, the consumption of petroleum has declined, which is contrary to what was predicted.



Graph 5a Petroleum Consumption Decomposition by Sector [13]

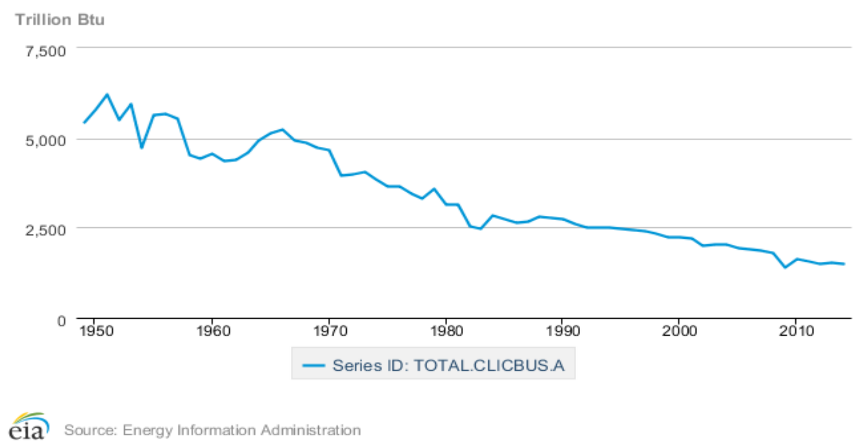


Graph 5b Petroleum Consumption Percentage by Sector [13]

In 2004, when the overall consumption of petroleum started to fall, the industrial sector's consumption was about 5.3 million b/d. In 2014, this consumption had declined to 4.5 million b/d, according to the EIA. Between 1996 and 2012, the net imports of petroleum were higher than the total field production of petroleum in the United States. The petroleum consumption in 2015 was projected to be 47 percent higher than the consumption in 2003. However, the consumption of petroleum in 2015 actually ended up being lower than that of 2003, which resulted in a denominated energy surprise in the United States. It is fairly easy to make the assumption that a reduction in oil prices in the United States would help cut expenses in national industries, increasing their profit. However, that is not the case. The industrial sector is not the biggest consumer of petroleum in the United States, and it does not represent a very large percentage of the surprise in 2014, nor is it expected to represent a large percentage in 2025. Graph 5a represents the difference of consumption projected in 2003 and the new projection realized in 2015. As it is possible to see, petroleum consumption by the industrial sector was never predicted to increase dramatically. In addition, graph 5b demonstrates that the industrial sector represented only 21 percent of the surprise in 2014, and that it is projected to reduce the amount of its influence to the surprise in 2025 to only 12 percent. This is a clear example and explanation that the industrial sector's consumption of petroleum was not expected to have a major increment in the upcoming decade. Moreover, petroleum consumption decrease has had a beneficial impact on the United States. "The drop in consumption relative to expectations has helped reduce U.S. net imports of petroleum by nearly half, reducing the dependence on foreign oil and our macroeconomic vulnerability to rises and falls in the world price of oil."[14] To conclude, it is very important to say that, indeed, lower prices of gas and a low consumption of petroleum helped the economy to improve, but did not have a direct major impact on the industrial sector in the United States. [9][13]

Coal

Coal, during the 1950s, used to be the most important source of energy for the industrial sector. This sector consumed 45.5 percent of the total coal production. That is not the case today, though. By the end of that decade, petroleum and natural gas became much more important sources of energy for the industrial sector. Although the overall consumption of coal started to increase in the 1960s, and reached a peak in 2011, the percentage consumed by the industrial sector started decreasing drastically at the same time. Graph 6 shows the amount of coal consumed by the industrial sector until 2013. In 2007, coal became the less used source of energy by the industrial sector. In 2013, although the total production of coal is larger than it was in 1950, the industrial sector consumed only 7% of it for energy purposes, while the electric production sector consumed 92.8% of the total amount of coal in order to produce electricity. It is important to know that, in this case, 10.5% of the total energy consumed by the industrial sector came from electricity retail sales to the sector in 2014. In summary, coal has become a less important source of energy for the industrial sector, and today, it represents no more than 5% of the total energy consumed by the industrial sector.



Graph 6 Coal Consumed Yearly by the Industrial Sector [16]

Renewable & Alternative

Contrary to coal, the use of renewable and alternative sources of energy by the industrial sector has been increasing very slowly over the years, and they are no longer the least-used sources of energy. In 2006, the industrial sector's consumption of energy from renewable and alternative sources was greater than the consumption of energy produced by coal, and it has been gradually increasing ever since. Even though renewable and alternative sources of energy do not have a major impact regarding the industrial sector's consumption, it is important to include a brief analysis of this information, since the overall consumption of renewable and alternative energy is becoming very popular due to the environmental benefits. More than 50% of the total generation of renewable energy is used to provide electric power. In addition, for the industrial sector, renewable energy represents only 10% of its total consumption, but about 24% of the total renewable and alternative energy generated is used to supply the industrial sector. Table 2 shows the increase in overall consumption of renewable and alternative energy from 2013 to 2015. Although the production and consumption of energy through a clean, renewable, and alternative method is gradually increasing, it can have a major impact on the industrial energy consumption in the future, in addition to the impact it is already having on the environment. [18]

Table 2 U.S Renewable Consumption [17]

E = estimated; P = Predicted

quadrillion Btu

	2013	2014	2015 E	2016 P
Hydroelectric power	2.561	2.467	*2.608*	*2.524*
Geothermal	0.221	0.219	*0.220*	*0.220*
Solar	0.307	0.426	*0.524*	*0.571*
Wind	1.595	1.750	*1.839*	*2.084*
Wood biomass	2.138	2.173	2.113	2.125
Ethanol	1.090	1.105	*1.094*	*1.094*
Biodiesel	0.205	0.194	*0.196*	*0.196*
Waste biomass	0.476	0.472	*0.489*	*0.495*
Total	9.321	9.554	*9.870*	*10.092*

Benchmarking Tools

In 2012, the industrial sector consumed 22% of the power in the United States. 39% of this consumption was energy generated with petroleum, and 43% with natural gas. In addition, a small percentage of 7% and 11% came from coal production and renewable energy production, respectively. According to the EIA, in 2013, the natural gas consumption increased by 3%. The reason for this is the large cost advantage of natural gas in the United States, relative to those in Japan and Europe. In 2011, most of the facilities with the ability to switch from oil to natural gas as a fuel or feedstock made this change, allowing them to capture a larger share of global markets. As previously mentioned, benchmarking is required by industrial and commercial companies to minimize their energy consumption, which, in turn, allows them to maximize earnings. Energy consumption can be a key factor when competing with other similar facilities. This thesis is focused on analyzing different benchmarking tools and techniques used by companies, both commercial and industrial, to benchmark their energy performance. An analysis of each of these tools will be performed individually and then compared. [3]

Industrial Assessment Centers

The Department of Energy (DOE) of the United States has created the Industrial Assessment Centers (IACs) located at twenty-four universities around the country. Their mission is to conduct energy audits for certain companies in order to improve their productivity, reduce waste, and save energy. In my opinion, they are a great advantage for these companies, since the IACs can provide a better service to their facilities, improving the energy efficiency of each company. In general, the work of the IACs consists of a very in-depth evaluation of the facility for which a service will be provided. For example, in the case of the Energy Solutions (ES) at North Caroline State University, a team consisting of engineering faculty and students (upper-level undergraduates and graduates) start with a pre-assessment analysis, which provides them with some background data on equipment types, utility bills, and usage patterns, prior to scheduling an assessment date. If the requirements are met, the team conducts a visit to the facility to take engineering measurements (energy, material waste, and productivity-related measurements) using diagnostic equipment. They also study the manufacturing process in order to start the detailed analysis. Based on the results, the team creates a plan with estimated costs, performance, and payback time for the company, and within sixty days, the company receives a confidential report detailing the work done and any recommendations for improvement. In six to twelve months, the manager of the facility and the IACs' team determine which recommendations will be implemented. In the case of ES, after twelve months, the team will contact the manager to check which recommended measurers have been or will be implemented.[4] [6]

Table 3 Example of an assessment on database. [5]

Assessment #OK0731

Assessment Year	2006
SIC	3713
SIC Description	Truck And Bus Bodies
NAICS	336120
NAICS Description	Heavy Duty Truck Manufacturing
Principal Product	Truck
Sales	$ 45,000,000
# of Employees	260
Plant Area (Sq.Ft.)	500,000
Annual Production	450 *Not Available*
Production Hrs. Annual	4,160
Location (State)	OK
Yearly Energy Cost	$ 610,906

Current Energy Usage & Costs

Energy Sources	Yearly Usage	Yearly Cost	Unit Price
Electricity	5,602,800 kWh	$ 240,591	$ 0.043 /kWh
- Demand Charge	15,080 kW	$ 92,496	$ 6.13 /kW
- Electricity Fees	-	$ 1,711	-
Natural Gas	30,296 MMBtu	$ 276,108	$ 9.11 /MMBtu
TOTAL ENERGY	87,725 MMBtu	$ 610,906	$ 6.96 /MMBtu
Water Disposal	5,010 Gal	$ 8,251	$ 2 /Gal

Recommended Reduction in Usage & Costs

Recommended
Implemented

Energy Sources	Yearly Savings	Yearly Cost	% Saved	Unit Price
Electricity	205,312 kWh 143,547 kWh	$ 9,536 $ 6,886	3.96 % 2.86 %	$ 0.043 /kWh
- Demand Charge	0 kW 0 kW	$ 0 $ 0	0.00 % 0.00 %	$ 6.13 /kW
- Electricity Fees	-	$ 0 $ 0	0.00 % 0.00 %	-
Natural Gas	12,034 MMBtu 682 MMBtu	$ 109,671 $ 6,213	39.72 % 2.25 %	$ 9.11 /MMBtu
TOTAL ENERGY	14,138 MMBtu 2,153 MMBtu	$ 119,207 $ 13,099	19.51 % 2.14 %	$ 6.96 /MMBtu
Water Disposal	0 Gal 0 Gal	$ 0 $ 0	0.00 % 0.00 %	$ 2 /Gal

Facilities that qualify to work with IACs have to be within the Standard Industrial Classification (SIC) 20XX-39XX, or within the North American Industrial Classification System (NAICS) 311XXX-339XXX. In addition, the facility has to be located less than 150 miles from the university and it has to have fewer than five hundred employees at the plant site. Monetarily, the gross annual sales have to be below $100 million, and the plant has to have energy bills higher than $100,000, but lower than $2.5 million. There is an online database with information about the different plants that have used the IACs to improve their energy efficiency. The database provides information regarding recommendations made to different plants around the United States, as well as different case studies. Table 3 represents an example of an assessment performed on a heavy-duty manufacturing plant.

IAC example case study

Lockheed Martin's Meridian plant solicited an audit to the Mississippi's State University IAC in 2002. The plant produced sales of $6 million, and due to their significant energy consumption, they have an approximate $158K budget for energy per year. The assessment was led by Center Director, Dr. B. K. Hodge, and Former Assistant Director, Dr. Richard Forbes, both professors in the Department of Mechanical Engineering at Mississippi State University. According to the case study, 38% of the consumption comprises heating, 16% motors, 14% compressed air, 21% lighting, and 11% HVAC miscellaneous systems. Since compressed air is expensive due to the amount of energy it needs to operate, the IAC team decided to focus on this area.

Table 4 Opportunities at Lockheed Martin's Meridian Facility. [7]

Recommended Action	Annual Resource Savings	Annual Cost Savings ($)	Implementation Cost ($)	Payback (months)
Compressed Air Systems Repair Leaks in the Compressed Air System	98.2 MMBtu/yr	$982	$477	6
Purchase New Compressor to Replace 30 year aged Compressor	N/A	$29,000	$79,245	33
Totals	**98.2 MMBTU/yr**	**$29,982**	**$79,722**	**32**

The first recommendation was to implement an "aggressive program to locate and fix the compressed air leaks," since it was found that a significant amount of air was being lost due to small leaks. The solution was implemented, resulting in an annual cost savings of $900. The second recommendation emerged from an observation of an unusual cost on maintenance of the facility's air compressor. The suggestion was to purchase a new 200 hp air compressor to be used as the primary compressor, and to keep an old one to be used as a backup. The maintenance cost was reduced from $30K to only $1000 per year. The initial cost of implementing both recommendations was almost $80K, but with a short payback period of only 2.7 years, as it is possible to appreciate on Table 4. [7]

ENERGY STAR's Energy Performance Indicators (EPIs)

ENERGY STAR is a voluntary program created by the U.S. Environmental Protection Agency (EPA) to help individuals, businesses, and industries improve their energy efficiency in order to minimize pollution and increase their monetary savings. "ENERGY STAR offers energy tracking and benchmarking tools to help manufacturers assess their energy performance, establish baselines, and set performance improvement goals."[4] The price of these types of softwares and systems sometimes limits small companies from acquiring them. For that reason, ENERGY STAR has the Energy Tracking Tool -- the simplest tool they offer for free -- that allows users to track energy data for specific facilities and for the entire organization, reporting out custom energy intensity metrics, such as MMBtu/unit of production. For bigger industries, ENERGY STAR offers a database that allows the industries to obtain Energy Performance Indicators in order to compare their performance to similar facilities. The following EPIs are currently available on the ENERGY STAR's website, and it is possible to download each of them individually:

- Automobile Assembly EPI
- Cement Manufacturing EPI
- Container Glass Manufacturing Plants EPI
- Cookie and Cracker Plants EPI
- Flat Glass Manufacturing Plants EPI
- Frozen Fried Potato Processing Plants EPI
- Integrated Paper and Paperboard Manufacturing Plant EPI
- Juice Processing Plants EPI

- Pharmaceutical Manufacturing EPI
- Pulp Mill EPI
- Wet Corn Milling EPI

Since it is very easy to compare the energy performance of different facilities with this tool, ENERGY STAR scores the performance of U.S. buildings and facilities on a scale of 1 to 100. If the facility receives a score of 75 or higher, then it is eligible to apply for ENERGY STAR certification. [19]

Pulp Mill Plants

The concept used for the EPIs can be described in terms of a standard linear regression model, with a simple linear equation that can be written as

$$E_i = \alpha + \beta\, y_i \tag{1}$$

where E is the energy use of plant i, and y is the production of plant i. The parameters α and β can be obtained from given data on energy use and production. This equation was later modified, taking into account random errors and the addition of important variables. The evolution of the equation throughout the years was based on comments from industry reviewers and further analyses. This evolution led to the final version of the EPI equation for pulp mill plants that is

$$\begin{aligned}\ln(energy) = \; & A + \beta_1 \ln(prodution) + \beta_2 Share\ of\ fiber\ as\ round\ wood \\ & + \beta_3 Share\ of\ production\ as\ special\ Alpha \\ & + \beta_4 Share\ of\ production\ asUnbleached\ Sulfate \\ & + \varepsilon \end{aligned} \tag{2}$$

where "Energy = total source energy (MMBTU); Production = production of pulp (short tons); Share of fiber as round wood= Ratio of round wood (whole tree) as a percentage of total fiber input; Share of production: Special Alpha= Ratio of Special Alpha as a share of production; Share of production: Sulfate, unbleached = Ratio of unbleached Sulfate as a share of production. The variable ε is distributed as N(0, σ2) and β is a vector of parameters to be estimated." Table 5 shows the estimated parameters for the model obtained from a sample size of twenty-eight plants. [20]

Table 5 Pulp Mill Model Estimates [20]

Variable	Estimate	Standard Error	t-ratio
Log Production*	1.051082	0.1206943	8.71
Share of fiber as round wood*	-1.079867	0.4420925	-2.44
Share of production: Special* Alpha	1.309212	0.4093806	3.2
Share of production: Sulfate, unbleached	-0.7259908	0.5532731	-1.31
Water Treatment	0.075191	0.286776	0.26
Constant	1.56077	1.389814	1.1
Error Distribution Parameters			
σ^2	. 4333		
R – square	.8153		
F(5, 22)	19.42		

Pulp Mill Example

In the case of the Pulp Mill factory, the company needs quite a bit of information to complete the analysis. This information includes the total amount of energy consumed, the total production during that specific year, the percentage of the production mix, and, finally, whether or not the plant includes a water treatment onsite. Based on this information, the EPI can be performed. Figure 1 shows the hypothetical data from factory "TEST1" and factory "TEST2" used to complete the table. Figure 2 presents the results of the performance of TEST1 and TEST2. The plots in the results are telling that plant TEST1 in year 2011 was doing better than 76% of other similar plants, and that plant TEST2 in 2010 was performing better than 59% of similar plants in 2011.

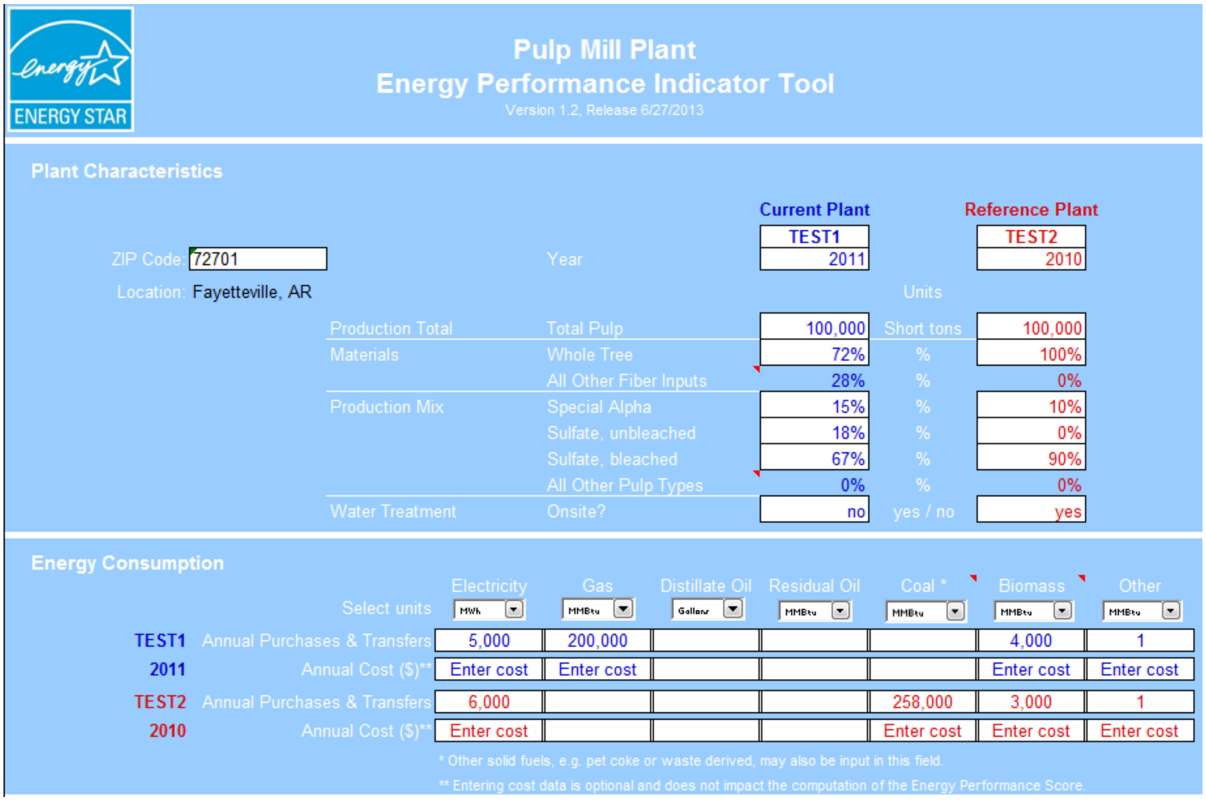


Figure 1 Input Data of Hipotetical Pulp Mill Plants [21]

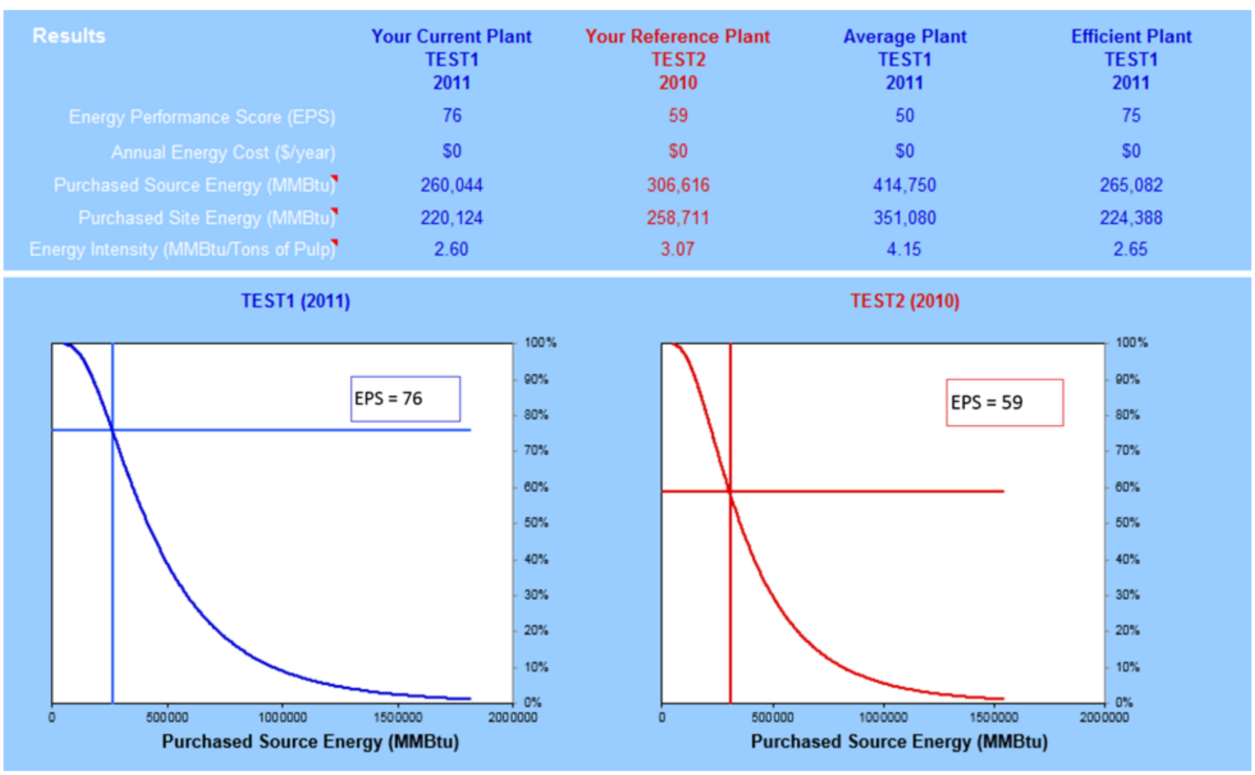


Figure 2 Results for Hypothetical Performance of two Plants [21]

The following step it to use the results obtained in a productive and effective manner. As previously mentioned, the scale that the ENERGY STAR tool uses has a range of 1 to 100. In the case of the example used, in year 2011, plant TEST1 scored a 76%. For that reason, TEST1 is a plant that is eligible to be rewarded, and one from which other similar plants should learn. Figure 3 reflects the strategy a specific plant should perform depending on the score obtained in their EPI.

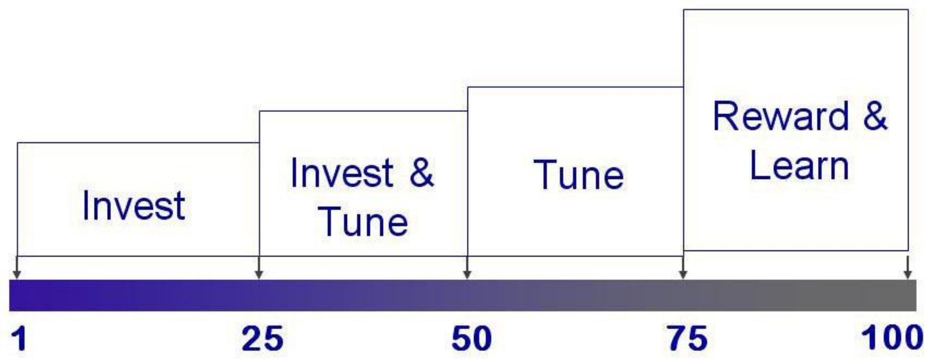


Figure 3 Energy Star Scores Scales/Strategy [22]

ENERGY STAR not only provides the tools to measure the energy performance of different types of plants, but, after the performance has been calculated, may also provide services and advice to build an energy management program. This is a five-step process that consists of identifying the type company/plant you have, and building a successful energy team that will take care of the process. All employees need to be aware and involved in the program for it to succeed. The final step is to "advance your energy program." [23]

ENERGY STAR has proven to be the most efficient and easy way to obtain energy performance indicators for organizations and plants. The benchmarking tools ENERGY STAR provides to obtain information about the energy standing of an industrial plant gives accurate information in order to be able to create a well-designed energy plan and program. The next step for the company/plant is to implement the plan, and to make sure it is being carried out appropriately, or, in other words, managed the right way.

DOE Energy Performance Indicators (EnPIs)

The DOE has their own downloadable version of EnPis called EnPIs-v4.0. The U.S. Department of Energy updated their version in October of 2014 for the last time. The software works similar to the ENERGY STAR one, and it is used in Excel, as well. The difference with the EnPI-v4.0 is that the file is an add-in that has to be installed in the user's computer. The add-in works as a "regression analysis tool to help plants and corporate managers establish a normalized baseline of energy consumption, track annual progress of intensity improvements, energy savings, Superior Energy Performance (SEP) EnIPs, and other EnPIs that account for variation due to weather, production, and other variables." [34]

Although both softwares work based on a regression analysis of data, the DOE EnPI-v4.0's algorithm is completely different. The DOE EnPI-v4.0's add-in uses the equations listed below to predict the energy consumption based on the independent variables entered by the user.

Table 6 DOE EnIP-v4.0 Equation Symbols and Definitions [36]

Symbol	Definition
y	Dependent variable predicted by the regression model (i.e. predicted energy use)
y*	Measured dependent variable (i.e. measured energy use)
p	Number of independent variables and coefficients
x_i (i=1, 2… p)	The ith independent variable from total set of p variables (i.e. production, HDD, CDD, etc.)
b_i (i=1, 2… p)	The ith coefficient corresponding to x_i
b_0	Intercept or constant
k=p+1	Total number of parameters including intercept
n	Number of observations
i=1, 2… p	Independent variables' index
j=1, 2..n	Data points index
R^2	Coefficient of determination
r	Residual (or error, or deviation)
SS_E	Residual (error) sum of squares (or regression sum of squares)
SS_R	Regression sum of squares
SS_T	Total sum of squares

"For the EnPI tool, the dependent variable is the energy consumption by the facility. The independent variables can be production, cooling degree days (CDD), heating degree days (HDD), etc. If the user selects more than one independent variable, a multivariable linear regression equation is needed to predict the dependent variable or energy consumption at the facility" with an equation to predict the dependent variable based on all the independent variables. [36] The general equation for a multivariable model is

$$y = b_0 + b_1 x_1 + b_2 x_2 + \cdots b_p x_p \tag{3}$$

Then, the residual, also known as the "error of deviation," is calculated, obtaining the difference between the predicted and the measured dependent variables. The error sum of squares (SSE) is calculated in order to minimize the error sum of squares. Microsoft Excel calculates the SSE for each combination of coefficients and determines the combination of coefficients that minimize the SSE. The coefficients that result in the lowest error sum of squares are entered into the regression model to produce an equation that can be used to estimate the dependent variable, given the independent variable(s)."[36]

The coefficient of determination (R^2) measures how well future outcomes are likely to be predicted by the model. A regression model is a good fit for the data if the R^2 value is close to 1. In order to calculate the R^2 value, the regression sum of squares (SSR) and the total sum of squares (SST) that need to be found first. The regression sum of squares is defined as

$$SS_R = \sum_j^n (y_j - y *_{avg})^2 \tag{4}$$

and the total sum of squares is calculated using the following equation:

$$SS_T = \sum_j^n (y *_j - y *_{avg})^2, where\ y *_{avg} = (\sum_j^n y *_j)/n \tag{5}$$

The total sum of squares is the sum of both the SSE and SSR.

With the results from the previous calculations, the coefficient of determination can be defined as

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_E}{SS_T} \tag{6}$$

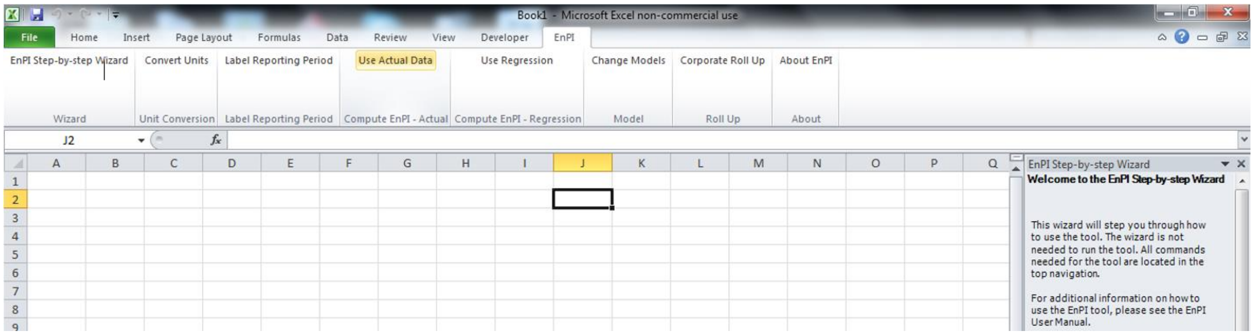


Figure 4 DOE EnPI-v4.0 add in Toolbar [34}

Figure 4 shows the top Excel toolbar that is installed with the software's add-in. If the user decides to use the DOE EnPI-v4.0, the spreadsheet has to be created from scratch. Due to the fact that the spreadsheets are not already created, the task of obtaining energy performance indicators is more difficult. For this reason, the U.S. Department of Energy provides users with an "En.IP V4.0 User Manual" [35] that can be found online and downloaded as a PDF file. Additionally, there is an online video that demonstrates how to use EnPI-v3.0, but it has not yet been updated.

Industrial Energy Analysis and Management

After analyzing their performance, facilities are required to start improving their energy performance and consumption. There is different tools available that provide the assistance for facilities to implement Energy Management Systems (EnMS) and plans/programs in order to achieve an efficient level of energy consumption. These tools are focus on providing the information on how to systematically continue developing the industrial energy consumption.

ENERGY STAR's Management method/tools

Benchmarking and the tools provided by ENERGY STAR can result in very precise information about a plant's energy performance. ENERGY STAR is not only the best tool to perform benchmarking, but also a very valuable tool to create and start an energy management program for any plant. The initial tool provided by ENERGY STAR is the Guideline for Energy Management, which can be found as a full PDF file with the complete process of management. Their strategy of creating a successful energy management program is focused on continuous improvements of energy performance. The ENERGY STAR process consists of seven steps.

The first step is to make a commitment to continuous improvement. "No matter the size or type of organization, the common element of successful energy management is commitment. Organizations make a commitment to allocate staff and funding to achieve continuous improvement." [24] The second step is to assess the performance of the plant/building in order to set a baseline. The EPIs provided by ENERGY STAR are a great tool to perform this assessment. With that information and a baseline set, it is possible to proceed to step three and set goals. "Setting clear and measurable goals is critical for understanding intended results, developing effective strategies, and reaping financial gains." [24] Step four is to create an action plan on how to meet the goals previously set. This plan can be modified overtime. The fifth step consists of implementing the action plan this way: 1) Creating a communication plan. 2) Raising awareness of goal among all the organization. 3) Build capacity through training and access to information and technology. 4) Motivation to achieve the goals among the stuff. 5) Track and control the progress in the company monthly. The sixth step in the management process is to evaluate the progress measuring the results obtained to compare them to the established goals. It also includes analyzing what worked and what did not, in order to make changes to the action plan. The seventh and final step is to provide recognition to anyone involved in the improvement of energy performance. This is substantial to increase motivation inside the organization. [24]

ENERGY STAR provides a free excel spreadsheet with a Facility Energy Management Assessment Matrix, which “outlines the key activities identified in the ENERGY STAR Guidelines for Energy Management and three levels of implementation: little or no evidence, some elements, and fully implemented.” [26] The tool basically allows the comparison of an organization’s program to the Guidelines by identifying the degree of implementation that most closely matches the facility's adoption of the corporate program. Figure 5 illustrates part of the spreadsheet.

ENERGY STAR® Facility Energy Management Assessment Matrix

Facility Name: Assessment Date:

	Little or no evidence	Some elements/degree	Fully implemented	Next Steps
Commit to Continuous Improvement				
Site Energy Leader	None assigned.	Assigned responsibilities but not empowered. 20-40% of time is devoted to energy.	Recognized and empowered leader having site manager and senior energy manager support.	
Site Energy Champion	None identified.	Senior manager implicitly supports the energy program.	Senior manager actively supports the energy program and promotes energy efficiency in all aspects of site operations.	
Site Energy Team	No site energy team.	Informal organization with sporadic activity.	Active cross-functional team guiding site energy program.	
Energy Policy	No energy policy or awareness of organizational policy.	Organizational policy in place. Little awareness by site energy team and limited application of policy.	Organizational policy supported at site level. All employees aware of goals and responsibilities.	
Accountability	No energy budgeting and accountability.	Estimates used for allocating energy budgets.	Key users are metered separately. Each entity has total accountability for their energy use.	
Participation Levels	No reporting of energy performance data internally or involvement in external organizations.	Some participation, sharing, mentoring, and professional memberships. Annual reporting of performance.	Participates in energy network/organizations. Shares best practices/mentors other sites. Reports usage quarterly.	
Assess Performance and Opportunities				
Track & Analyze Data	Limited metering or tracking. No demand analysis or billing evaluation.	Some metering, tracking, analyzing, and reporting. Energy bills verified for accuracy.	Key loads metered, tracked, analyzed, and reported. Facility peak demand analyzed. Adjusts for real-time demand.	
Documentation	No manuals, plans, designs, drawings, specs, etc. for building and equipment available.	Some documentation and records available. Some review of equipment commissioning specs conducted.	Critical building and equipment documentation available and used for load surveys/recommissioning/efficiency goals.	
Benchmarking	Energy performance of systems and facilities not benchmarked.	Limited comparisons of specific functions, or only same-site historical comparisons.	Key systems/sites benchmarked using comparison tools like Portfolio Manager/Energy Performance Indicators.	
Technical Assessments	No formal or external reviews.	Limited review by vendors, location, or organizational and corporate energy managers.	Extensive regular reviews by multi-functional team of internal and external professionals. Full assessment every 5 years.	
Best Practices	None identified.	Ad hoc or infrequent monitoring of trade journals, internal databases, and other facilities' best practices.	Regular monitoring of trade journals, internal databases, and other facilities. Best practices shared and implemented.	
Set Performance Goals				
Goals/Potential	Energy reduction goals not established.	Loosely defined. Little awareness of energy goals by others outside of site energy team.	Potential defined by experience or assessments. Goals roll up to unit/site/corporate/organization and status posted prominently.	

Figure 5 Part of the ENERGY STAR Facility Assessment Matrix [26]

The "Next Step" column can be used to improve the management in the facility, or simply to make sure the process will be done similarly due to good performance and improvements. Using the results obtained, ENERGY STAR suggests further actions in order to restart the seven-step cycle to modify what needs to be changed, and to keep what was working correctly moving. With this tool, ENERGY STAR has provided facilities the ability to keep improving their energy performance year by year.

Additionally, ENERGY STAR provides another complete Assessment Matrix called the Energy Tracking Tool (ETT). This extremely complex tool allows users to track energy use, energy intensity, energy cost, greenhouse gas emissions, and progress toward goals on a monthly or annual basis for the organization and facility [26][27][28]

DOE Management tools

The Department of Energy also provides tools to organizations to improve their energy consumption and management. The eGuide is an online tool that is especially useful for companies who are looking to improve energy management, in that it starts with the beginning steps at the bottom, and then works its way up to the top, where the final steps are located.

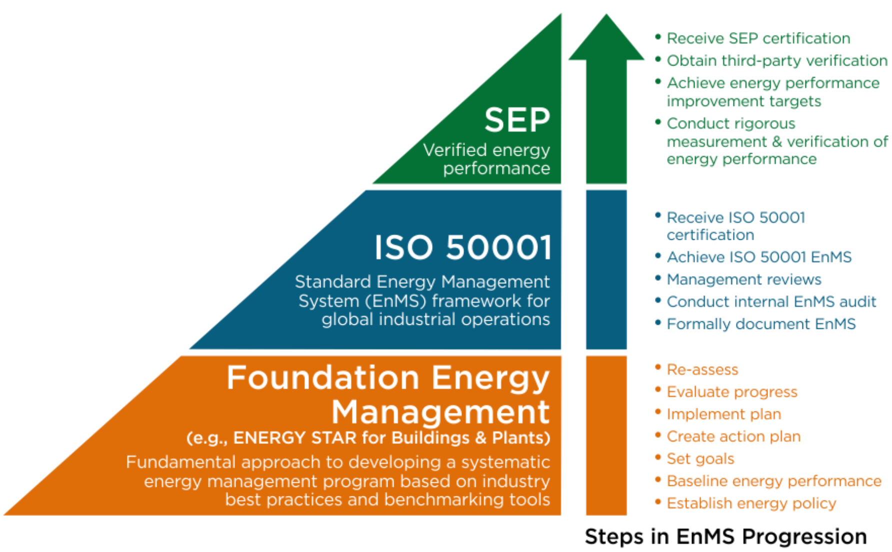


Figure 6 Strategic Energy Management Checklist [32]

Figure 6 shows a simplified eGuide's Strategic Energy Management Checklist, and the levels on which a company will be positioned after meeting the requirements on the checklist. A complete checklist for each level can be found on their website.

Level 1, the Foundation Energy Management, is designed to help any organization from any sector implement a basic energy management program. This is the perfect starting point for any company. Level 2 is the ISO 50001. It helps an organization implement an energy management system (EnMS) that conforms to the ISO 50001-2011 standard. Finally, the highest level of EnMS is the Superior Energy Performance (SEP). To reach this level, an organization has to build upon ISO 50001 by achieving additional requirements. The eGuide provides an online procedural list of instructions and requirements written step-by-step, and can lead any organization to improving their EnMs. [31]

ISO 50001 Standard & Superior Energy Performance SEP

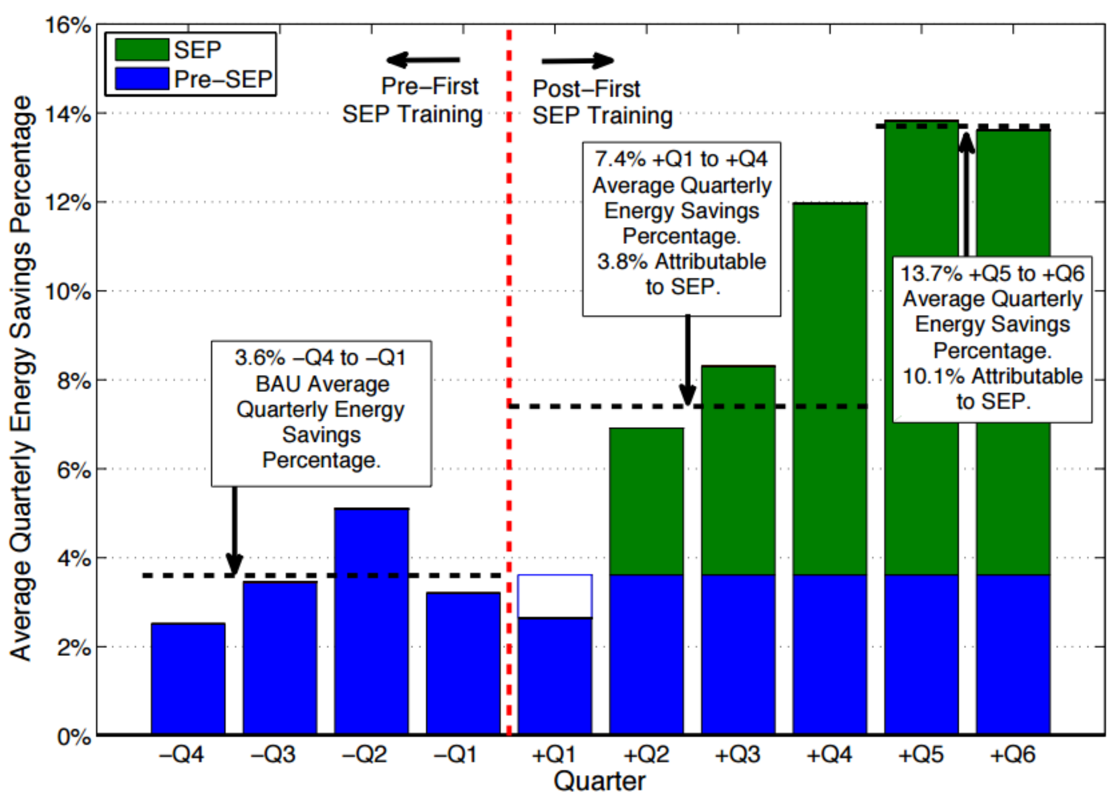
Although ENERGY STAR and ISO 50001 (International Organization for Standardization) are voluntary tools that manufacturers can use to improve they energy efficiency and management programs, their certifications do not mean the same. "The purpose of this International Standard is to enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use and consumption. Implementation of this International Standard is intended to lead to reductions in greenhouse gas emissions and other related environmental impacts and energy cost through systematic management of energy. This International Standard is applicable to all types and sizes of organizations, irrespective of geographical, cultural or social conditions."[30] As recommended by the EPA, organizations looking to obtain certification of an energy management system to ISO 50001 should first meet all aspects of the ENERGY STAR guidelines for energy management. The reason is because, in contrast to ENERGY STAR's certification that says an organization's energy performance is high compared to other organizations in the same industry, ISO 50001 certifies that a facility or organization meets the defined energy management requirements. In other words, ISO 50001 certifies the energy management system of an organization. [29]

Figure7 Plan-Do-Check-Act Method [31]

ISO's technique to improve energy is based on the Plan-Do-Check-Act (PDCA), which incorporates energy management into an organization's everyday practice. The "Plan" part consists of conducting an energy assessment and establishing a baseline, the energy performance indicators, the objectives, and the targets and action plans to deliver results that will improve the energy performance. The "Do" part is only to implement the energy management action plans. For the "Check" part, one must monitor and measure processes and the key characteristics of operations that determine energy performance against the energy policy and objectives, and report the results. Finally, the "Act" part accounts for taking action to continually keep improving the energy performance, as well as the Energy Management system (EnMS).[30][31]

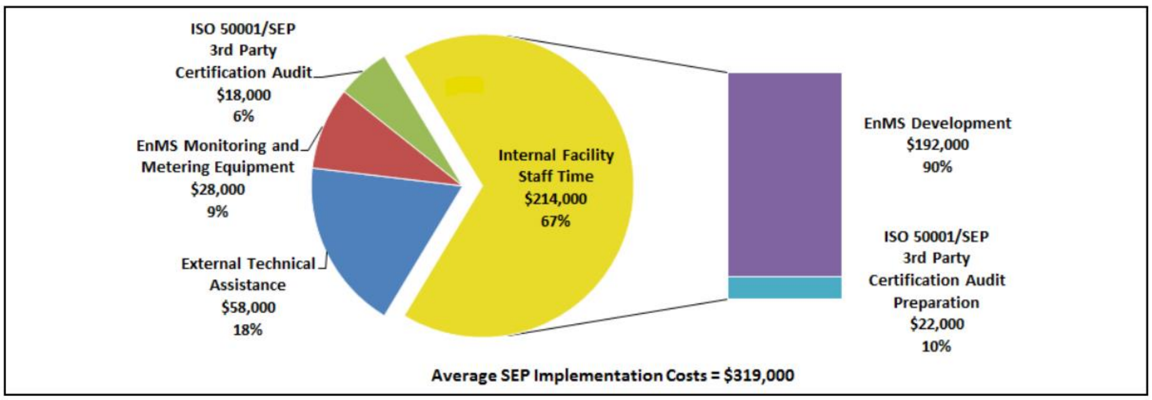
Similarly to ISO 50001, "Superior Energy Performance is a certification program that verifies improvements in energy management and performance in industrial facilities." [29] To obtain the SEP certification, organizations are required to use ISO 50001 energy management standards, as well as the American National Standard, ANSI/MMSE 5021. SEP is considered the highest energy management certification. As it is possible to see in Figure 5 (page 21), the requirements to achieve a Superior Energy Performance include all the requirements to be certified with ENERGY STAR and ISO 50001.

SEP is important for any plant and organization due to the fact that it uses the ISO 50001 energy management system, “which helps an organization institutionalize the policies, procedures, and tools to systematically track, analyze, and continually improve energy performance, including energy efficiency, use, and consumption.”[29] In the United States, nine plants with a SEP certification have achieved $87,000 to $984,000 in annual savings from energy consumption. As an example of the effectiveness of being a SEP certified facility, the first industrial facilities to obtain SEP certification improved their energy performance from 6% to more than 25% in only three years. Graph 7 represents the energy savings percentage for nine companies implementing the SEP program. It is possible to see that prior to the first SEP training, energy performance improved by an average of 3.6% against the baseline during each quarter. The energy savings percentage increases to 7.4% for the year during quarters +Q1 to +Q4 and 13.7% during quarters +Q5 to +Q6. The reason there is a clear increase in savings between the first and the second year after the first SEP training is because the first year dedicated to implementing a well-designed EnMS. These levels of energy savings are expected after the implementation of the ISO 50001 EnMS. [37]



Graph 7 Average Quarterly Energy Savings Percentage [37]

There is a price in the process of implementing the required steps to achieve a SEP certification. According to the “Assessing the Costs and Benefits of the Superior Energy Performance Program” [37] paper, the average cost of implementation for nine facilities was $319,000. The cost is higher for bigger facilities, while the cost reduces for smaller ones. This average cost includes the implementation of the ISO 50001 EnMS. Graph 8 is the representation of the breakdown of the costs of implementation of the programs. As seen, the largest portion of the costs represents the costs inside the facility. “Average staff time was 1.7 FTE and ranged from 1.1 FTE to 3.5 FTE or an average internal cost of $214,000 with a range of $141,000 to $432,000 over 1.1 years.”[37] This range of internal costs is based on the nine companies that had been analyzed.



Graph 8 ISO 50001 & SEP Program Implementation Participation Costs [37]

The payback period for the nine facilities analyzed indicated that those facilities with consumption greater than 0.27 TBtu of energy should not surpass two years. On the other hand, if their consumption is lower, then the payback period can increase for up to eight years, which is the case for one of the facilities whose consumption was about 0.125 TBtu. Depending on their consumption per year, and the payback period each facility achieved, they attained a Gold or Platinum level of certification. [37]

Conclusion

Industrial energy consumption has been increasing throughout the years. Energy consumption signifies major expenses for manufacturing facilities and a variety of different organizations. In order to minimize their energy consumption and expenses due to energy, and maximize production and profit, the industrial sector had to start controlling and improving their use and management of energy. Industries and the way they control their energy consumption is called benchmarking, and benchmarking has been helping all types of industries to reduce energy consumption. The first method or option companies have to improve their energy consumption is the Industrial Assessment Centers, located at twenty-four different universities in the United States. These assessment centers are in charge of completing a full analysis of the hiring facility's energy consumption, and must analyze each form in which energy could possibly be being wasted or not used appropriately. After completing the analysis on the plant, the assessment center's group has to develop a plan and strategies focused to minimize the plant's consumption. This plan is sent to the plant, and it is the company's decision whether or not to implement the full plan, part of it, or none of it. If the full plan or part of it is implemented, the assessment center group keeps track of the consumption to see if the consumption was reduced after a certain period of time.

A second option to minimize energy consumption is to implement the program created by ENERGY STAR. ENERGY STAR was created by the Environmental Protection Agency with a focus on energy consumption and its environmental impact. ENERGY STAR provides a tool which helps industries measure their consumption of energy and compare their standing to facilities in the same type of industry, based on their annual production and energy consumption. These results, known as Energy Performance Indicators, helped facilities to improve their energy efficiency and consumption. ENERGY STAR certifies facilities that rank over the 75% in their type of industry.

A similar tool to control a facility's energy consumption was created by the Department of Energy. This software allows facilities to create a database with their consumption and production, which allows them to obtain Energy Performance Indicators similar to the ones obtained with the ENERGY STAR tool. The main difference between these two benchmarking tools it that the ENERGY STAR one can only be used by certain types of industries, while the tool created by the U.S. DOE can be used by any facility, organization, or company.

Energy Performance Indicators are useless if facilities and organizations do not have an appropriate energy management system (EnMS). Management systems are different methods organizations can use to keep track of their improvement in energy consumption, compared to a baseline defined after their first assessment. ENERGY STAR offers a simple way to keep track of a good energy management with a list of procedures that the organization or facility needs to follow. More advanced and complex strategies of energy management are the ISO 50001 and the Superior Energy performance programs. These two require the companies to pay for the program, and implement it in order to start the process to first become a certified by ISO 500001, and later, once higher-level goals are achieved, by SEP. These programs have shown the importance of having a well-designed energy program, and the benefits of them.

Benchmarking and the implementation of energy management systems have statistically demonstrated the reduction of energy consumption in the industrial sector. The variety of tools and programs presented in this paper are a proof that energy efficiency can be achieved by any organization and facility in the industrial sector. Energy consumption will keep increasing in the future, while the industrial sector keeps expanding, but energy benchmarking and energy management will allow the United States’ industry sector to maximize energy efficiency and minimize environmental impact, thanks to the availability of benchmarking tools

Acronyms

Bcf/d – Billion cubic feet per day

Btu – British Thermal Unit

BUA – Business As Usual

DOE – Department of Energy

EIA – U.S. Energy Information Administration

EPA – Environmental Protection Agency

EPIs or EnPIs – Energy Performance Indicators

EnMS – Energy Management System

ES – Energy Solutions at North Carolina State University

ETT – Energy Tracking Tool

FTE – Hours worked by one employee on a full-time basis

IACs – Industrial Assessment Centers

ISO – International Organization for Standardization

PDCA – Plan-Do-Check-Act

SEP – Superior Energy Performance

SIC – Standard Industrial Classification

TBtu – tera British Thermal Unit (x10^12)

References

[1] "EIA - Independent Statistics and Analysis." EIA.gov BETA. Accessed August 2015. http://www.eia.gov/beta/MER/?tbl=T02.01#/?f=M

[2] "Total Energy Data." EIA.gov BETA. Accessed August 2015. http://199.36.140.204/beta/MER/index.cfm?tbl=T01.03#/?f=A

[3] "Natural Gas Use for Power Generation Falls as Industrial Sector's Use Continues to Rise." EIA.gov. Accessed August 2015. http://www.eia.gov/todayinenergy/detail.cfm?id=14031

[4] "Industrial Assessment Centers (IACs)." Energy.gov - Office of Energy Efficiency and Renewable Energy. Accessed September 2015. http://energy.gov/eere/amo/industrial-assessment-centers-iacs

[5] "IAC Database." IAC: Industrial Assessment Centers. Accessed September, 2015. https://iac.university/#database.

[6] "The Department of Mechanical and Aerospace Engineering." Mechanical and Aerospace Engineering, NC State University. Accessed September 2015. http://www.mae.ncsu.edu/energy/code/iac.htm%2520%255b6

[7] "Lockheed Martin: Industrial Energy Assessment Finds Potential Savings from Aircraft Assembly Company." Mississippi State: U.S. Department of Energy. May 22, 2002. Accessed September 2015. PDF.

[8] Ratner, Michael, and Carol Glover. "U.S. Energy: Overview and Key Statistics." Congressional Research Service. June 27, 2014. Accessed November 2015. https://www.fas.org/sgp/crs/misc/R40187.pdf.

[9] "Energy Consumption by Sector." U.S. Energy Information Administration - Monthly Energy Review. Last modified November 2015. Accessed December 1, 2015. http://199.36.140.204/totalenergy/data/monthly/pdf/sec2.pdf.

[10] "Natural Gas Use for Power Generation Falls as Industrial Sector's Use Continues to Rise." EIA.gov - Independent Statistics and Analysis. Accessed November 2015. http://www.eia.gov/todayinenergy/detail.cfm?id=14031.

[11] "Henry Hub Natural Gas Spot Price (Dollars per Million Btu)." EIA.gov. Last modified November 15, 2015. Accessed November 2015. http://www.eia.gov/dnav/ng/hist/rngwhhdm.htm.

[12] "Natural Gas Chart." Investing.com. Accessed November 2015. http://www.investing.com/commodities/natural-gas-streaming-chart.

[13] "Explaining the U.S. Petroleum Consumption Surprise." The White House. June 1, 2015. Accessed November 2015. https://www.whitehouse.gov/sites/default/files/docs/explaining_us_petroleum_consumption_surprise_final.pdf.

[14] Deese, Brian, and Jason Furman. "The Boon of Reduced Oil Consumption." Washington Post. June 18, 2015. Accessed November 2015. https://www.washingtonpost.com/opinions/the-boon-of-reduced-oil-consumption/2015/06/18/c02c43a4-146c-11e5-9ddc-e3353542100c_story.html.

[15] "How We Use Energy, Industry." The National Academies of Sciences. Last modified 2015. Accessed November 2015. http://needtoknow.nas.edu/energy/energy-use/industry/.

[16] "EIA Open Data." EIA.gov. Accessed November 2015. http://www.eia.gov/opendata/qb.cfm?sdid=TOTAL.CLICBUS.A.

[17] "Renewable & Alternative Fuels." EIA.gov. Last modified September 24, 2015. Accessed November 2015. http://www.eia.gov/renewable/.

[18] "EIA's Energy in Brief: What Are the Major Sources and Users of Energy in the United States?" EIA.gov. May 30, 2014. Accessed November 2015. http://www.eia.gov/energy_in_brief/article/major_energy_sources_and_users.cfm.

[19] "History." Energystar.gov. Accessed November 2015. https://www.energystar.gov/about/history

[20] Boyd, Gale, and Yi Guo. "Development of ENERGY STAR® Energy Performance Indicators for Pulp, Paper, and Paperboard Mills." Energystar.gov. Accessed November 2015. https://www.energystar.gov/sites/default/files/buildings/tools/Pulp_and_Paper_EPI_Documentation_FINAL_0.pdf.

[21] “Pulp Mill Plant Energy Performance Indicator Tool.” Microsoft Excel Ver. 1.2. June 27, 2013. Energy Star.

[22] "ENERGY STAR Energy Performance Indicators for Plants." Energystar.gov. Accessed November 2015. http://www.energystar.gov/buildings/facility-owners-and-managers/industrial-plants/measure-track-and-benchmark/energy-star-energy.

[23] "Build an Energy Management Program." Energystar.gov. Accessed November 2015. https://www.energystar.gov/buildings/facility-owners-and-managers/industrial-plants/build-energy-management-program.

[24] "Guidelines for Energy Management." Energy Star. Accessed December 1, 2015. PDF.

[25] “Energy Tracking Tool.” Microsoft Excel Ver. 1.0. February 1, 2010. Energy Star.

[26] “Facility Energy Management Assessment Matrix.” Microsoft Excel download from Energystar.gov.

[27] "ENERGY STAR & ISO 50001." Energystar.gov. Accessed November 2015. https://www.energystar.gov/buildings/facility-owners-and-managers/industrial-plants/build-energy-management-program/advance-your-energy-0.

[28] "The ENERGY STAR Guidelines for Energy Management." Energystar.gov. Accessed November 2015. http://www.energystar.gov/buildings/about-us/how-can-we-help-you/build-energy-program/guidelines.

[29] "Superior Energy Performance FAQs." Energy.gov. Last modified September 1, 2014. Accessed November 1, 2015. http://www.energy.gov/eere/amo/downloads/superior-energy-performance-faqs#What-is-SEP.

[30] "ISO 50001:2011(en) Energy Management Systems — Requirements with Guidance for Use." ISO.org. 2011. Accessed November 2015. https://www.iso.org/obp/ui/#iso:std:iso:50001:ed-1:v1:en.

[31] "AMO Energy Resources Center EGuide." U.S. Department of Energy. Accessed November 2015. https://ecenter.ee.doe.gov/_layouts/ecenter/ppc.eguide/home.aspx.

[32] "AMO Energy Resources Center Strategic Energy Management Checklist." U.S. Department of Energy. Accessed November 2015. https://ecenter.ee.doe.gov/EM/SPM/Pages/SEM_home.aspx.

[33] “eGuide Levels, Steps and Substeps.” U.S. Department of Energy. 2014. PDF.

[34] “Energy Performance Indicator.” U.S. Department of Energy. Excel add-in software download.

[35] “EnPI V4.0 User Manual.” U.S. Department of Energy. October 21, 2014. PDF.

[36] “Department of Energy Advanced Manufacturing Office EnPI V4.0 Tool Algorithm.” U.S. Department of Energy. September 11, 2014. PDF.

[37] Therkelsen, Peter, Ridah Sabouni, Aimee McKane, Tracy Evans, and Paul Scheihing. "Assessing the Costs and Benefits of the Superior Energy Performance Program." 2013 ACEEE Summer Study on Energy Efficiency in Industry, Niagara Falls, NY. July 2013. PDF.

[38] Couvillion, Rick. "Industrial Energy Metrics." Lecture, Arkansas Manufacturing Solutions Energy Workshop, Fort Smith, AR, December 11, 2013.